CAD-BASED CALCULATION OF CUTTING FORCE COMPONENTS IN GEAR HOBBING

BY

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Abstract. One of the most commonly used gear manufacturing process especially for external is gear hobbing. The optimisation of the process of gear hobbing is of great importance in the modern industry. This paper presents a novel simulation program called HOB3D, that can simulate the cutting process in a commercial CAD environment, thus producing results with the optimal precision. The outputs of the program include the 3D chip and gap geometry as well as the developing cutting forces which were validated using experiments.

Key words: gear hobbing, cutting forces, simulation.

1. Introduction

One of the key components of any torque transmission system is high precision involute gears. Gears can be constructed with a wide variety of methods; Gear hobbing is the one mainly used in the modern industry. Gear hobbing kinematics consists of three relative motions between the cutting tool and the workpiece. This makes it difficult to simulate with analytical models. HOB3D is a novel simulation program based on a commercial CAD environment which can simulate the cutting process and provide results including 3D solid chips and gaps as well as predicting the developing cutting forces.

2. State of the art

The research conducted in the area of gear hobbing can be divided into two categories: gear hobbing process simulation and wear prediction. In the first field a series of simulation models have been developed using CAD [1,2], FEA [3] or analytical [4-7] based models. Experiment based models [8-9] are used in the field of wear prediction order to calculate the wear of the cutting tool and optimize the cutting so as to obtain uniform wear along the cutting tool. Cutting forces prediction is an area of great interest also. Research conducted in this area is based on Kienzle-Victor’s equations and depend on geometry of chips.

3. Gear Hobbing and HOB3D simulation process

Gear hobbing kinematics is based on three relative motions between the cutting tool and the workgear. These motions must be synchronised in order to
produce high quality helical and spur gears. As presented in Fig. 1 the work gear rotates round its axis while at the same time the hob rotates round its own axis and moves parallel to the gear axis. The hob is positioned in an angle relative to the gear. The magnitude of this angle is relative to the hob helix angle and the helix angle to the gear produced correspondingly.

![Gear hobbing principle and kinematics](image)

**Fig. 1 – Gear hobbing**

Gear hobbing process is affected by a series of parameters which can be divided in three categories: hob, gear and process parameters. The first include module (m), external diameter (d_h), number of origins (z_1) and number of columns (n_i) of the hob. Gear parameters are number of teeth (z_2), helix angle (ha) and gear width. Finally, process parameters include axial feed (f_a) and cutting speed (v). A series of parameters can be calculated from those above mentioned, those being distance e, the helix angle of the hob (γ), gear diameter (d_g) and depth of cut (t).

In order to simulate the process of gear hobbing, new software has been developed. The proposed simulation model has been embedded in a commercial CAD program thus taking advantage of its accuracy resulting in more detailed calculations.

The new simulation code called HOB3D uses three coordinate systems in order to calculate the results required. The first (1) is positioned on the examined cutting edge and has the x axis parallel to the hob’s axis, the y axis perpendicular to x axis and finally z axis perpendicular to the prior two. Coordinate systems (2) and (3) have axis z running through the work gear’s axis. In coordinate system (2), x axis is always rotating in order to point to the gap, while the axes of coordinate system (3) are fixed.
Fig. 2 presents the flowchart of this simulation model. As it is illustrated, after all the input data, shown on the top side of the figure, has been defined, the initial workpiece is developed in the CAD environment and the number of the effective teeth is determined accordingly. The gear hobbing simulation process is executed for
all these teeth. The first step in the simulation process is the positioning of the cutting edge on the 3D space. This positioning is repeated along the path that is covered by the cutting edge. The profiles that arise are combined in order to form a 3D surface. The next step is the creation of an assembly that includes the workgear and the 3D surface. Afterwards, Boolean operations are used in order to generate the 3D chip and the 3D gap. The above described process is repeated for all active teeth in every rotation of the cutting tool. Finally, after the end of the simulation process the cutting forces on every one of the active teeth of the hob are calculated. These forces are added up and the total cutting forces are calculated.

4. HOB3D formulation

4.1. Simulation formulation

In HOB3D all the movements involved in the process are transferred to the hob cutting tooth motion. Furthermore, the simulation process is carried out on one gap of the gear thus reducing the simulation time. In order to identify the cutting teeth, those are numbered. The tooth which has the local axis Y₁ parallel to local axis X₂ when it passes through the center of the gap is named Tooth 0, the tooth that passes after that is named Tooth 1 and the tooth previous to that is named Tooth-1 and so on.
The simulation process is illustrated on Fig. 3. As it is presented, the hob profile according to Din3972 [10] must be designed first. This profile is presented on the top left frame of fig. 3 and positioned on the 3D space, as illustrated on the next frame of fig. 3. The positioning is repeated for a series of times until the tooth is out of the cut. After this step, there is a series of profiles correctly positioned on the 3D space. Every profile represents a revolving position of the hob and its positioning includes hob rotation, workpiece rotation and feedrate. All these profiles are combined in order to form a 3D surface like the one seen in the last frame of the first line of fig. 3. Then, the 3D surface is assembled with the 3D gap produced from the previous tooth. The final stage of the simulation process is the extraction of the final gap geometry and the non-deformed chip geometry. This is achieved with the aid of Boolean operations, as supported by the used CAD environment.

4.2. Force component calculation formulation

After the simulation is completed, the cutting forces can be calculated. The force calculation code is performed in accordance with Kienzle-Victor’s
equations. The calculation process is based on sections made on every one of the solid chips.

A series of sections are made for every chip. Each section is made in the plane of the hob’s cutting edge. The planes are visible on the top left frame of fig. 4. After the creation of the section on the 3D chip, the crosssection is discretised along the cutting edge. This discretisation is presented on the top right frame of fig. 4. The three force components are calculated according to the elementary chip width and thickness for every elementary chip section. The three force components are rotated in order to match the local coordinate system (1) and then added up in order to produce the total cutting forces on every crosssection. After all the sections are calculated the total forces on the tooth are obtained, as presented on the bottom of fig. 4.
4.3. Simulation results

HOB3D has been used in order to produce the 3D solid chips in the full cut phase of gear hobbing. These chips were analysed so that the cutting forces are calculated. The crossections made on the chip are presented on the right side of fig. 5 whereas the chip thickness on six of the crossections is illustrated on the left side of the same figure.
The cutting forces components for the above chip are presented in the next fig. 6 which are calculated in accordance with the system 1.
5. Verification

The verification of the force calculation module was conducted in two phases. First, the cutting forces simulated on specific teeth were compared to the ones measured by Bouzakis [4] while other cutting forces calculated by HOB3D were compared to the ones measured by Gutmann [5]. Fig. 7 illustrates the results of the first phase of the verification. As it can be seen, each column of the figure illustrates the measured and calculated cutting forces on one generating position measured on the coordinate system of the 3D gap (2). In most of the cases the simulation code predicts not only the form but also the magnitude of the cutting forces.

Fig. 7 – Comparison between calculated and measured cutting forces

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m = 3.79 \text{ mm}, \alpha_r = 20^\circ, h_a = 0^\circ, z_1/z_2 = 1/56, n_t = 9, d_r = 150 \text{ mm}, \\
f_a = 4 \text{ mm} / \text{ rev}, v = 120 \text{ m/min}, 16 \text{ MnCr5 BG, P25, Climb hobbing}
\]
The second step of the verification is the comparison between measured and calculated forces for all the cutting teeth simultaneously. Fig. 8 presents the comparison between the measured and the calculated cutting forces in all three directions of the coordinate system (3).

![Graphs showing comparison between calculated and measured cutting forces](image)

Fig. 8 – Comparison between calculated and measured cutting forces

### 4. Conclusion

1. A novel simulation model for gear hobbing, developed in a commercial CAD environment is presented in this paper. The model can simulate the manufacturing of helical as well as spur gears.

2. The developed model can predict the cutting forces components with great accuracy. The calculated forces have been verified with the aid of cutting experiments.
REFERENCES


